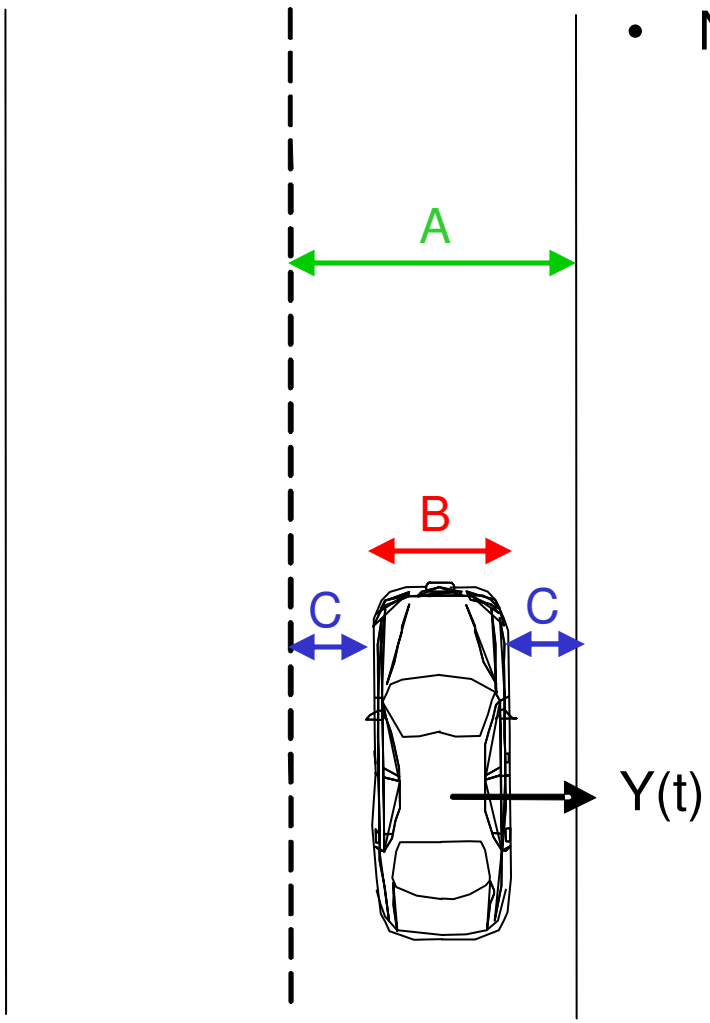
Objective Data Collection

- Relevant vehicle data:
  - Steering angle, lane position, accelerator pedal position, brake pressure, …
- Relevant scenario data:
  - Timing of number reading task, lateral deviation profile/timing, LDW mode, …
- Video Data. Quad-split digital video of the drive:
  1. View of the driver from passenger side B-pillar
  2. The forward view of the driving scene
  3. View of the driver's face from the DSM
  4. View of the IVIS screen

Methods: Lateral Deviation



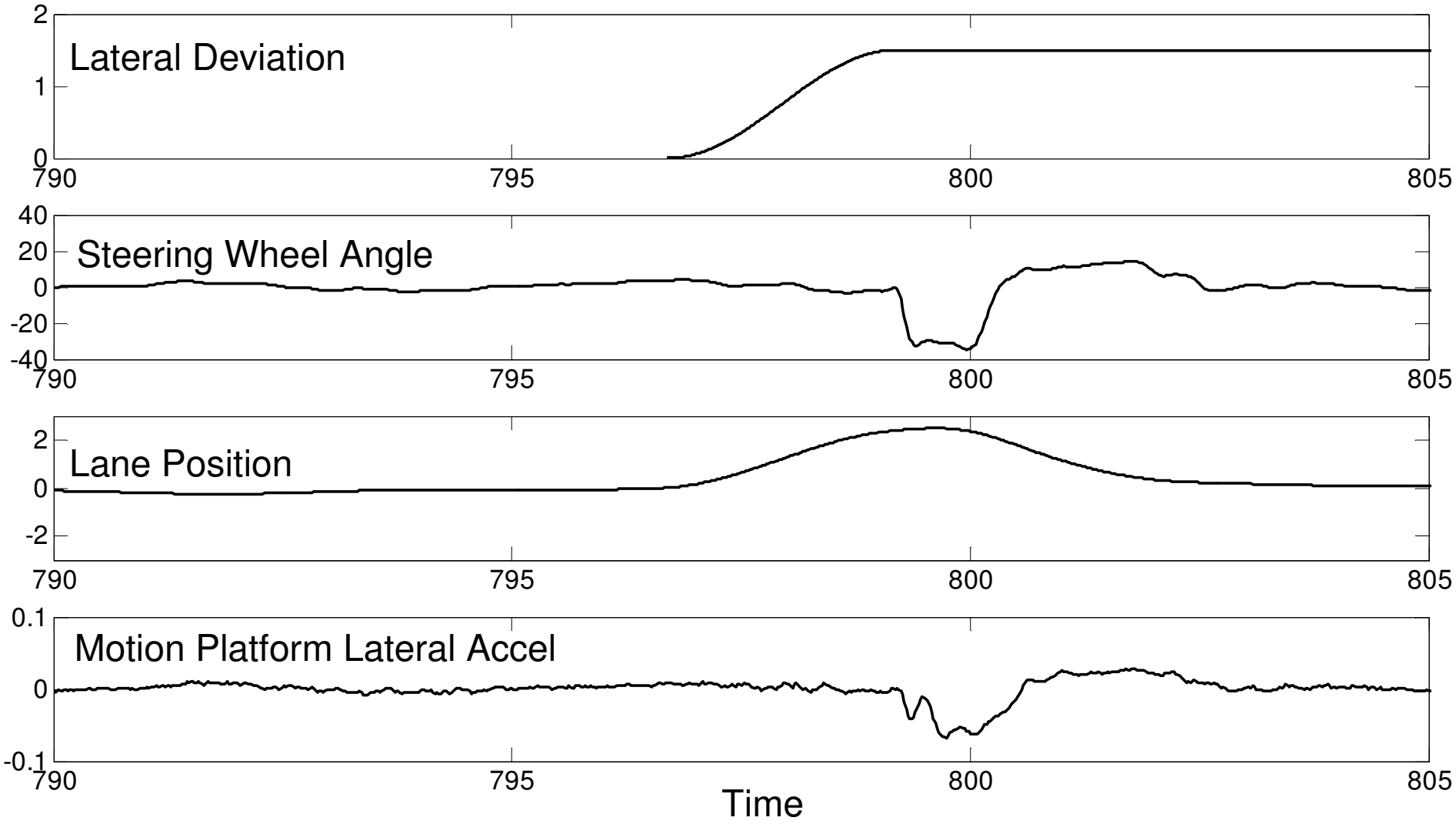
- Non-physical "lateral deviation" Y(t)
  - A small lateral profile is added to everything except the motion control system
  - Most drivers believe they generated the lane departure

A: Lane width = 3.37m (11 ft)

B: Vehicle width = 2.07m (82 in)

C: Vehicle centered in lane has ~0.65m from vehicle edge to lane edge

Lateral Deviation Example



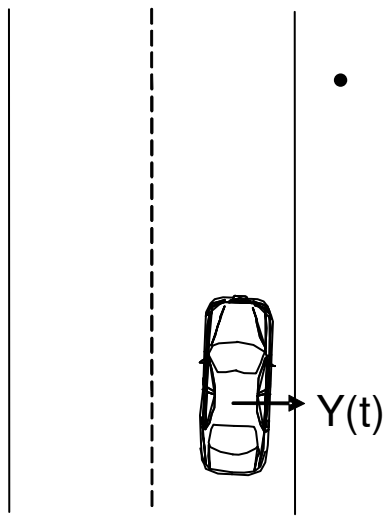
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

- SAVE-IT LDWs generated ~1ft past shoulder line
  - Previous VIRTTEX studies have shown that drivers are fairly vigilant for a 20-30 minute drive and rarely go past the shoulder line by more than 1 foot. [Also, see Nuisance warnings below]
  - **Change to system:**
    - Decreased lane width parameter by 0.8 m (+/-0.4 m ⇔ +/- 1.3 ft)
    - LDWs are generated when tire hits shoulder line (vehicle moves 0.65m laterally from center of lane)
- Nuisance warnings
  - Elimination of nuisance warnings is a benefit with the adaptive LDW. Drivers will see little difference/benefit without nuisance warnings in non-adaptive mode. Thus, we need to generate nuisance warnings in the non-adaptive condition.
  - **Change to system:**
    - Reduced definition of lane width by +/-0.4 m achieves this.
    - Pilot data indicates that drivers get ~4-5 nuisance warnings in non-adaptive mode

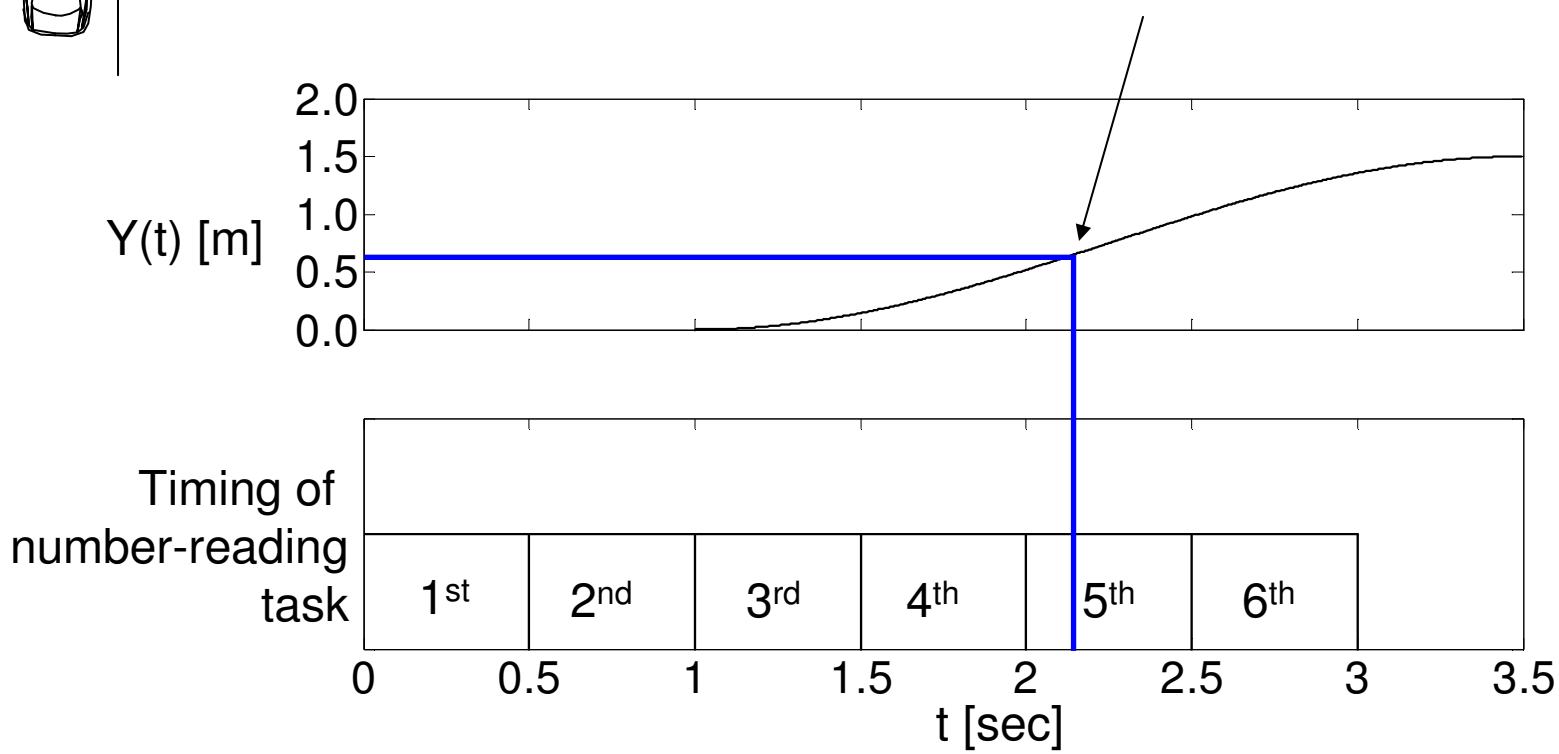
Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

- True positive during adaptive LDW
  - If the driver isn't registered with correct timing for adaptive LDW mode, then they will not get a true positive during the entire adaptive LDW segment. [Need 2 seconds of distraction, with at least 1 second in lane before departure]
  - Adjusting climate control and VIRTTEX number reading tasks are only tasks where drivers have a good chance of meeting conditions for adaptive LDW
  - **Change to study :**
    - Only the VIRTTEX number reading task is used with lateral deviation

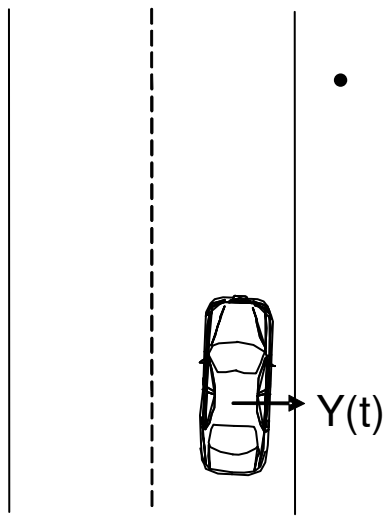
Methods: Lateral Deviation



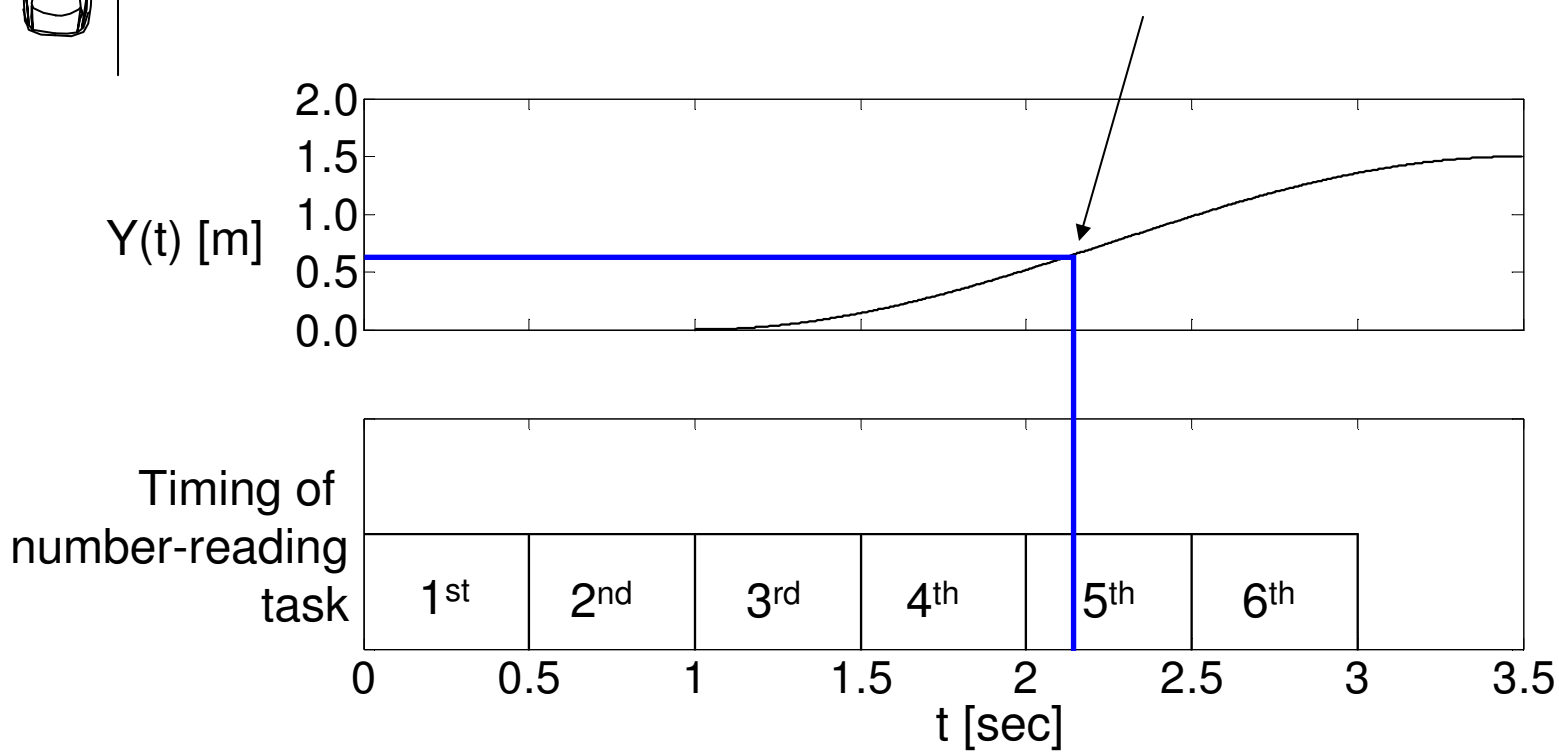
- Non-physical "lateral deviation" – a small lateral profile is added to everything except the motion control system
  - Most drivers believe they generated the lane departure
  - Parameters adjusted so LDW is generated ~2 seconds into number-reading task (car moves laterally 0.65m)



Methods: Lateral Deviation



- Consequence of timing
  - Not much time after onset of LDW before end of task
  - Likely that driver will be completing task at same time they are reacting to the LDW.

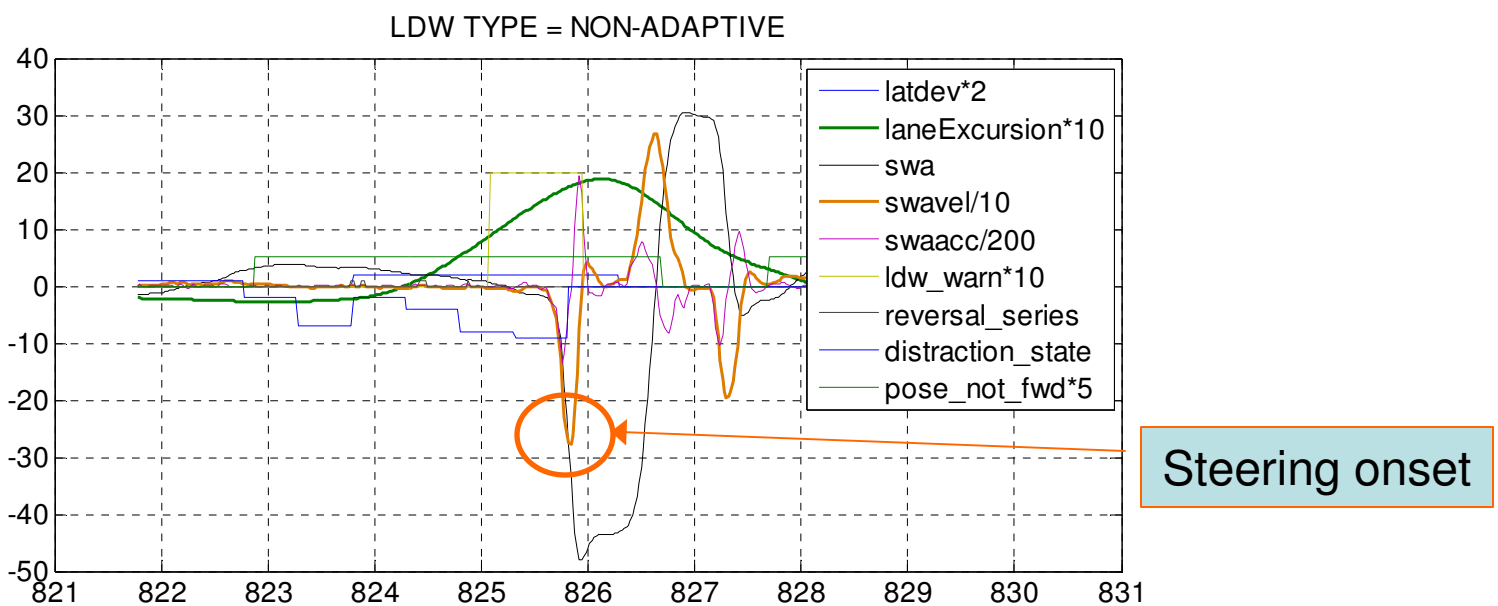


Results: Analysis of Lateral Deviation Events

- Data culling for drivers departing lane to the right
  - Each driver experienced a lateral deviation during both non-adaptive and adaptive LDW modes
    - Start with N = 40 possible events for each mode
  - **Non-Adaptive LDW (N = 37)**
    - 2 drivers caught the lateral deviation and did not receive a LDW
    - 1 driver caught the lateral deviation, but received a warning by over-correcting (LDW on left side)
  - **Adaptive LDW (N = 38)**
    - 1 driver caught the lateral deviation and did not receive a LDW
    - 1 driver caught the lateral deviation, but received a warning by over-correcting (LDW on left side)
    - **Note: 7 drivers departed the lane and did not receive a LDW (more on this later…)**

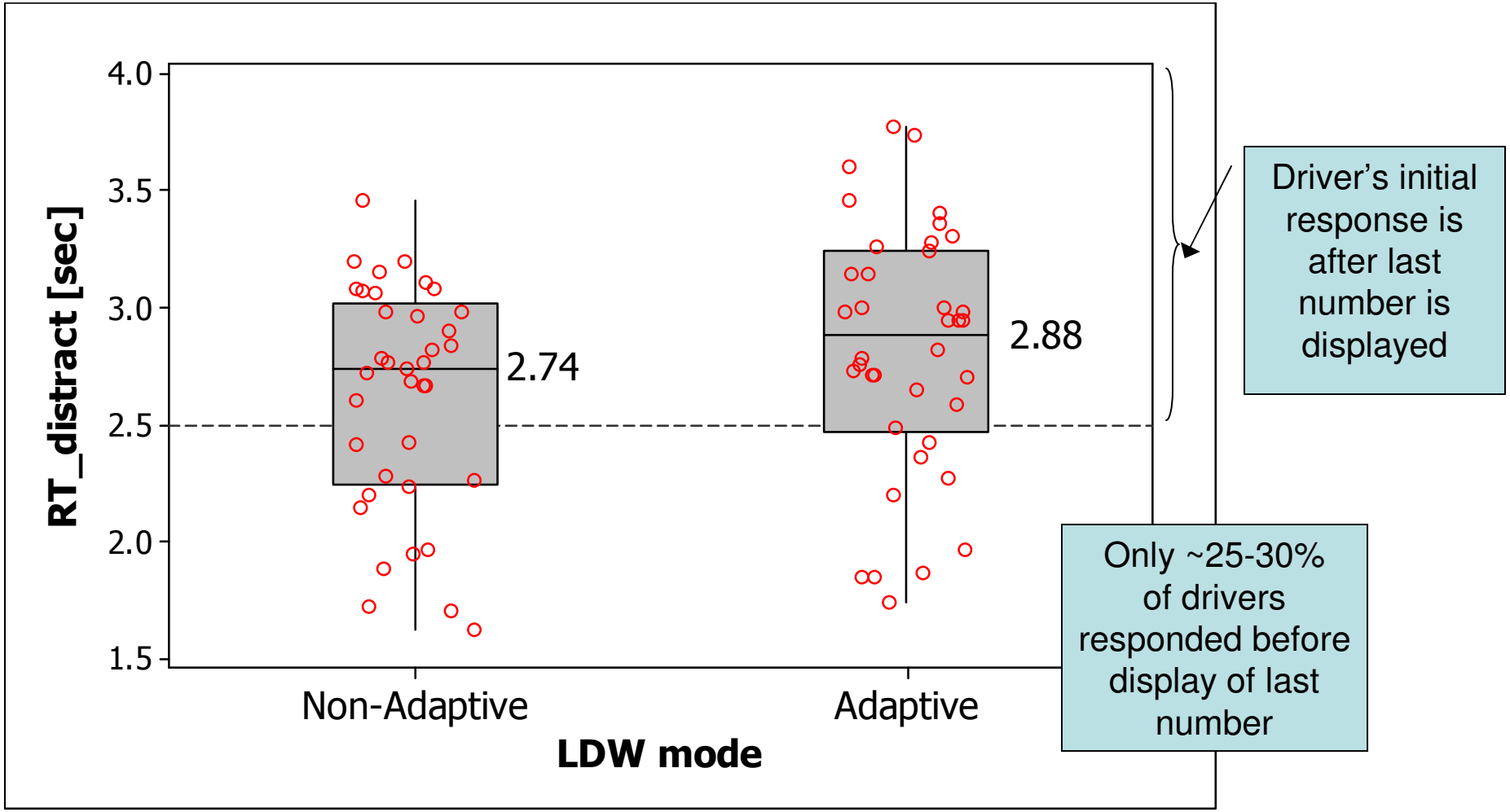
Results: Analysis of Lateral Deviation Events

- Driver response is onset of steering correction
  - CAMP algorithm used to calculate steering onset
    - All calculated compared to drivers' videos
    - 7 responses (9%) modified based on comparison of driver video and vehicle data (e.g. "double-steer")



Results: Analysis of Lateral Deviation Events

- Response Time: Time from **start of distraction task** until steering onset



Results: Analysis of Lateral Deviation Events

- Response Time: Time from **start of distraction task** until steering onset
- ANOVA with pooled errors for
  - Gender
  - All interactions ≥ 2nd order

Data transformed by $y' = y^2$ to meet normality assumptions of ANOVA

General Linear Model: TR_RT_distract [sec] versus LDW_mode

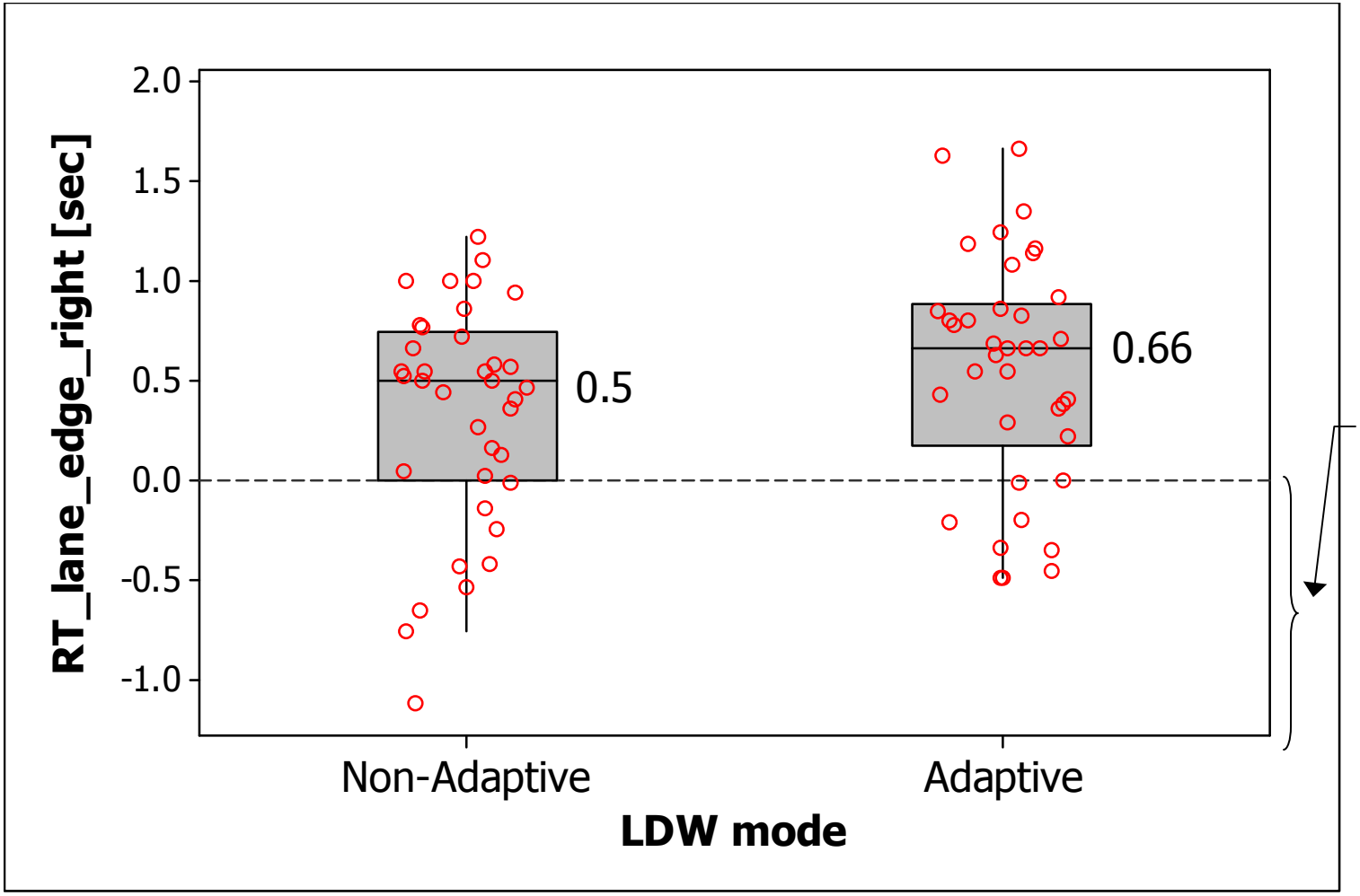
Factor	Type	Levels	Values
LDW_mode	fixed	2	0, 1

Analysis of Variance for TR_RT_distract [sec], using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
LDW_mode	1	22.243	22.243	22.243	**3.07**	**0.084**
Error	73	529.592	529.592	7.255		
Total	74	551.835				

Results: Analysis of Lateral Deviation Events

- Response Time: Time from **lane departure** until steering onset



Driver's initial response is before lane departure

(but not enough to overcome lateral deviation)

Results: Analysis of Lateral Deviation Events

- Response Time: Time from **lane departure** until steering onset
- ANOVA with pooled errors for
  - Gender
  - All interactions ≥ 2nd order

Data transformed by $y' = y^2$ to meet normality assumptions of ANOVA

General Linear Model: TR_RT_lane_edge_right [sec] versus LDW_mode

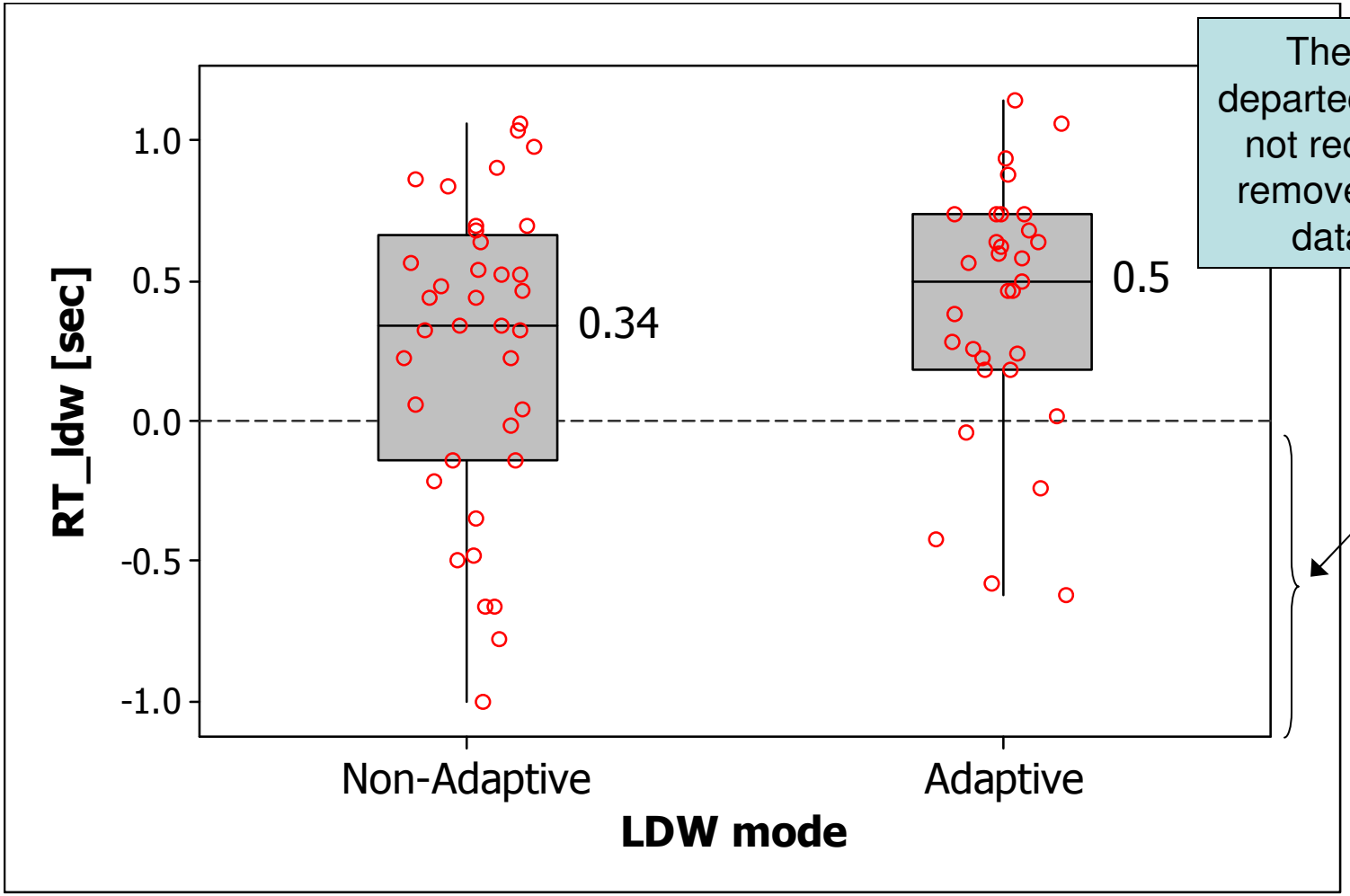
```
Factor     Type   Levels  Values
LDW_mode   fixed       2  0, 1

Analysis of Variance for TR_RT_lane_edge_right [sec]_1, using
Adjusted SS for
     Tests

Source     DF   Seq SS   Adj SS  Adj MS     F      P
LDW_mode    1   21.382   21.382  21.382  2.96  0.090
Error      73  527.534  527.534   7.226
Total      74  548.916
```

Results: Analysis of Lateral Deviation Events

- Response Time: Time from **LDW** until steering onset
- ANOVA: LDW mode is not statistically significant

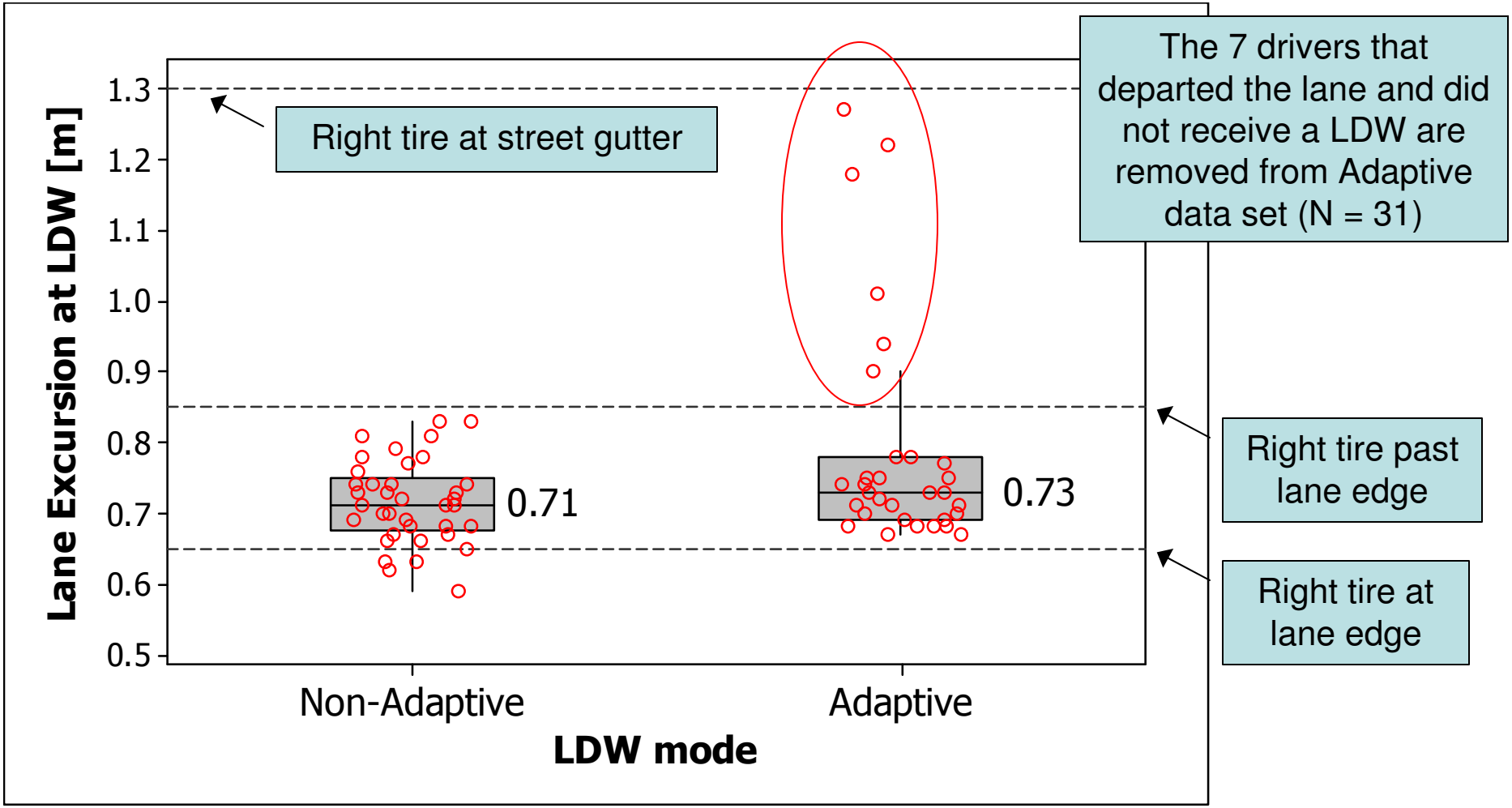


The 7 drivers that departed the lane and did not receive a LDW are removed from Adaptive data set (N = 31)

Driver's initial response is before LDW

Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 6 drivers in Adaptive mode had delayed activation of LDW
  - Delay caused by requirement that Pose Not Forward = 1 for at least 2 sec



Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 6 drivers in Adaptive mode had activation of LDW past lane edge
  - **Delay caused by requirement that <u>Pose Not Forward</u> = 1 for at least 2 sec**
  - Sub 8:
    - Driver starts out near lane edge
    - PNF = 1 near end of 1st number
  - Sub 18:
    - Slight steering bias to right as reading numbers
    - PNF = 1 near end of 1st number
  - Sub 22:
    - Slight steering bias to right as reading numbers
    - PNF = 1 near end of 1st number
  - Sub 31:
    - Slight steering bias to right as reading numbers
    - PNF = 1 near end of 1st number
  - Sub 16:
    - PNF = 1 initially, then briefly went to 0 even though driver was still looking down
  - Sub 40:
    - Slight steering bias to right as reading numbers
    - PNF = 1 near in 3rd number even though visually distracted at beginning

<u>4 drivers:</u> delayed activation caused by 2-second rule

<u>2 drivers:</u> delayed activation caused by DSM registration and 2-second rule

Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 7 drivers in Adaptive mode experienced no LDW during lane departure
  - **Caused mostly by 2-second distracted rule, and DSM registration issues**

1 driver: effected by 2-second rule

2 drivers: effected by DSM registration

4 drivers: effected by DSM registration and 2-second rule

  - Sub 3:
    - DSM reg
    - Driver lo
  - Sub 6:
    - Combina
    - By the ti within 2
  - Sub 10:
    - DSM registration issue; driver originally registered as PNF = 1, but then PNF = 0 right before departing lane
  - Sub 11:
    - DSM registration issue; driver registered as PNF = 0; driver rotated head to read numbers
  - Sub 19:
    - DSM registration issue; driver originally registered as PNF = 1
    - Driver then did check-glance; PNF went to 0 and stayed at 0 even after going back to task
  - Sub 34:
    - Combination of DSM registration, 1-second in lane rule
    - By the time the DSM registered distracted, the driver departed the lane in less than 1 sec
  - Sub 39:
    - DSM registration issue; always registered as PNF = 0; driver rotated head to read numbers

Summary for Driver and LDW system performance

- Difficult to ascertain differences in driver reaction time to lane departure
  - Not much time after lane departure before end of task
  - Most drivers (~70-75%) were completing task at same time they were reacting to the lane departure

- 13 drivers (33%) in Adaptive mode experienced delayed activation of LDW or no LDW
  - 6 drivers experienced delayed activation of LDW
    - Combination of 2-second rule and DSM registration issues
  - 7 drivers never experienced a LDW even though they departed the lane
    - 6 of 7 due at least partly to DSM registration issues
    - 5 of 7 due at least partly to 2-second distracted rule

- Evaluation of Workload Managers is very dependent on system algorithms and parameters

Results: Analysis of Adaptive Mode During Lateral Deviation Events

- 7 drivers in Adaptive mode experienced no LDW during lane departure
  - Caused mostly by 2-second distracted rule, and DSM registration issues
  - Sub 3:
    - DSM registration was reasonable
    - Driver looked forward and PNF registered as 0 right before slightly departing the lane
  - Sub 6:
    - Combination of DSM registration,
    - By the time the DSM registered di within 2 seconds. Also departed la
  - Sub 10:
    - DSM registration issue; driver orig before departing lane
  - ub 11:
    - DSM registration issue; driver registered as PNF = 0; driver rotated head to read numbers
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2-sec rule

2-sec rule
DSM registration

2-sec rule
DSM registration

DSM registration

2-sec rule
DSM registration

2-sec rule
DSM registration

DSM registration

1 driver: effected by 2-second rule
2 drivers: effected by DSM registration
4 drivers: effected by 2-second rule and DSM registration

Research and Advanced Engineering

Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

- Large variation in lane position at LDW activation
  - SAVE-IT LDW algorithm appears to use yaw rate and lateral rate as inputs. Although these are likely useful inputs, this will be a confounding variable (i.e. noise) in generating LDWs, and also driver's development of a mental model for adaptive LDW.
  - **Change to system:**
    - Set yaw rate to 0 (CAN message 0x600)
    - Set lateral rate to 0 (CAN message 0x4E2)
- SAVE-IT LDWs generated ~1ft past shoulder line
  - Previous VIRTTEX studies have shown that drivers are fairly vigilant for a 20-30 minute drive and rarely go past the shoulder line by more than 1 foot. [Also, see Nuisance warnings issue on next slide]
  - **Change to system:**
    - Decreased lane width parameter by 0.8 m (+/-0.4 m ⇔ +/- 1.3 ft) (CAN message 0x4E2).
    - LDWs are generated when tire hits shoulder line (vehicle moves 0.65m laterally from center of lane)

Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

- Nuisance warnings
  - Elimination of nuisance warnings is a benefit with the adaptive LDW. Drivers will see little difference/benefit without nuisance warnings in non-adaptive mode. Thus, we need to generate nuisance warnings in the non-adaptive condition.
  - **Change to system:**
    - Reduced definition of lane width by +/-0.4 m achieves this.
    - Pilot data indicates that drivers get ~4-5 nuisance warnings in non-adaptive mode
- Sensitivity of DSM
  - DSM is not registering drivers as being distracted for most of the tasks. The most reliable tasks for getting "distracted" registrations are adjusting climate control and VIRTTEX number reading.
  - **Change to system:**
    - Delphi re-calibrated DSM

Implementation Issues And Resolutions After Pilot Testing (with Delphi concurrence)

- True positive during adaptive LDW
  - If the driver isn't registered with correct timing for adaptive LDW mode, then they will not get a true positive during the entire adaptive LDW segment. [Need 2 seconds of distraction, with at least 1 second in lane before departure]
  - Adjusting climate control and VIRTTEX number reading tasks are only tasks where drivers have a good chance of meeting conditions for adaptive LDW
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